

Searching for coherent pulsations in ultraluminous X-ray sources (Research Note)

V. Doroshenko¹, A. Santangelo¹, L. Ducci^{1,2}

¹ Institut für Astronomie und Astrophysik, Sand 1, 72076 Tübingen, Germany, e-mail: doroshv@astro.uni-tuebingen.de

² ISDC, Department of Astronomy, Université de Genève, chemin d'Écogia, 16, CH-1290 Versoix, Switzerland

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ABSTRACT

Luminosities of ultraluminous X-ray sources (ULXs) are uncomfortably large if compared to the Eddington limit for isotropic accretion onto stellar-mass object. Most often either supercritical accretion onto stellar mass black hole or accretion onto intermediate mass black holes is invoked the high luminosities of ULXs. However, the recent discovery of coherent pulsations from M82 ULX with *NuSTAR* showed that another scenario implying accretion onto a magnetized neutron star is possible for ULXs. Motivated by this discovery, we re-visited the available *XMM-Newton* archival observations of several bright ULXs with a targeted search for pulsations to check whether accreting neutron stars might power other ULXs as well. We have found no evidence for significant coherent pulsations in any of the sources including the M82 ULX. We provide upper limits for the amplitude of possibly undetected pulsed signal for the sources in the sample.

Key words. X-rays: binaries, X-rays: galaxies, Stars: neutron, Stars: black holes

1. Introduction

Ultraluminous X-ray sources (ULX) are vaguely defined as non-nuclear extragalactic sources with luminosities exceeding $\sim 10^{39}$ erg s⁻¹, i.e. the Eddington limit for isotropic accretion on stellar-mass black hole (Feng & Soria 2011). These sources are considered, therefore, best candidates to host intermediate mass black holes (IMBHs, Colbert & Mushotzky 1999). Alternatively, super-eddington accretion onto stellar mass black holes like in the case of the well known source SS 433 (King et al. 2001; Fabrika 2004). Emission from young rotation-powered pulsars (Medvedev & Poutanen 2013) has been suggested as a possible mechanism powering ULXs.

Recently, the discovery of coherent X-ray pulsations from ULX M82 X-2 (or X-1) (Bachetti et al. 2014), with period of ~ 1.37 s and the associated orbital motion, provided a new explanation for the very bright emission of at least some of these objects. Based on the X-ray timing Bachetti et al. (2014) have derived a mass function of $f = 2.1 M_{\odot}$. The accretion would then proceed from a low mass companion via Roche-lobe overflow, likely the only mechanism to feed enough matter to explain the observed luminosity. This implies a strong spin-up torque imposed onto the neutron star in agreement with the observed short spin-up timescale ($P/\dot{P} \sim 300$ yr) and spin period of the pulsar. In principle, other ULXs powered by an accreting neutron star could exist and are expected to have spin periods of the order $\lesssim 10$ s as well.

Currently there is a lack of detailed studies of the variability in ULXs at short timescales as illustrated by the surprising discovery of the pulsations in M82 ULX, which is a rather well studied system. Motivated by this, we performed a targeted search for coherent pulsations with periods in range 0.15-15 s in archival *XMM-Newton* data to understand whether other ULXs might host accreting pulsars. In the present note, we report results of this systematic search.

2. Source sample and available data

The number of ULXs and candidates is steadily increasing since the launch of the *Einstein* satellite. Many of them are, however, not sufficiently bright for detailed timing analysis. As an initial step, we limited our analysis to a sample of fifteen bright ULXs observed with *XMM-Newton*. This sample was used by Heil et al. (2009) to characterize ULX variability in a broad frequency range and no significant periodicities were reported by these authors. However, Heil et al. (2009) did not search for coherent pulsations.

We searched for pulsation in archival *XMM-Newton* data of the EPIC PN camera as it is one of the few instruments with adequate timing resolution to investigate variability up to sub-second timescales. Our analysis is based on a larger dataset compared to the one considered by Heil et al. (2009) since many additional observations have become available since their publication. Most of the observations were performed in full-frame read-out mode with time resolution of ~ 0.07 s. The list of the sources in our sample, and the summary of available observations are presented in Table 1.

3. Data analysis and results

Low-level data reduction was carried out using the *XMM SAS* 13.5 package, current calibration files and standard filtering criteria¹. Source photons with energies in 0.3-10 keV range were then extracted using the source-centered circles with radius of 20'' in all cases except M82, where we used a radius of 40'' centered in between the two nearby ULXs, X-1 and X-2, where the pulsations could potentially originate from (Bachetti et al. 2014). The arrival times of individual photons were then corrected to solar barycenter using the *barycen* task.

To search for pulsations, we used the H-test (de Jager et al. 1989) applied to unbinned source events. Taking into account

¹ <http://xmm.esac.esa.int/sas/current/doc>

that in ULX M82 the pulsed fraction showed large variations with time (suggesting the possible transient nature of the pulsations), we analyzed individual observations separately. Results are summarized in Table 1.

We have found no evidence for significant periodic signals in any of the sources. Therefore, we followed the approach suggested by Brazier (1994) to derive the upper limits on amplitude of potentially present but undetected periodic signal f_{pulsed} . For each source and observation we calculated the upper-limit on the amplitude of a sinusoidal signal with period in the range 0.15-15 s at 3σ confidence level (for detail see Eq. 3 and accompanying text in Brazier 1994). We report in Table 1 the highest upper-limit among all the observations available for a given source. Note that for ULX in M82 our limit is below the lowest value reported by Bachetti et al. (2014).

A periodogram for the longest *XMM* observation of the pulsating ULX in M82 and periodograms for simulated sinusoidal signals with period of 1.37 s and pulsed fractions of 2.2%, and 5% is presented in Fig. 1. Simulated signals correspond to the derived upper limit for this observation, and to the lowest amplitude reported for *NuSTAR* in 0.3-10 keV energy range. Note, that in both cases pulsations are clearly detected (although with less than 3σ significance for $f_{pulse} = 2.2\%$). Surprisingly, no signal is evident in the *XMM* data.

Table 1. List of sources included in the analysis. Upper limits on pulsed fraction represent strongest (among all observations) limits at 3σ confidence level.

Source	Exp.(ks)/obs.	f_{pulsed} limit, %
M82 X-1/X-2	143/11	2.2
NGC 55 ULX	130/3	4.4
NGC 253 PSX-2	69/7	9.8
NGC 1313 X-1	315/18	4.4
NGC 2403 X-1	66/4	8.8
Holmberg II X-1	76/7	3.7
Holmberg IX X-1	195/13	4.6
NGC 3628 X-1	40/1	17.1
NGC 4395 X-1	91/3	8.6
NGC 4559 X-1	31/1	11.7
NGC 4861 ULX	19/3	30.7
NGC 4945 X-2	39/2	25.7
NGC 5204 X-1	82/8	8.1
M83 ULX	31/2	30.5
NGC 5408 X-1	473/10	3.6

4. Conclusions

Inspired by the recent discovery of the pulsations from the ULX in M82 with *NuStar*, we revisited the available archival *XMM-Newton* observations of several bright ULXs in order to systematically search for pulsations whose detection escaped previous investigations (as it was the case for ULX in M82). We found no significant pulsed signal in range of periods from 0.15 to 15 s in any of the considered sources including the ULX in M82. We provide, therefore, upper limits for pulsed fraction of potentially non-detected pulsations. Note, that in many cases these limits are rather weak due to limited statistics and could be significantly improved with additional observations.

For ULX M82 our upper limit turns to be a factor of two lower than the lowest value $f_{pulsed} \sim 5\%$ reported by Bachetti

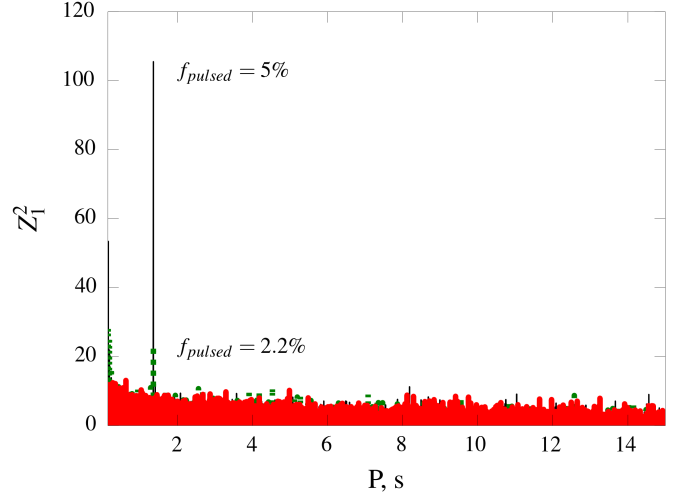


Fig. 1. A periodogram for the longest observation of the pulsating in ULX in M82 (thick red line, obsid 0206080101, exposure of 46 ks), and periodograms for simulated sinusoidal signal with pulsed fractions of 5% (thin black line, only visible at the peak) and 2.2% (dotted green line) with same exposure, observation duration and total number of photons as observed.

et al. (2014), and therefore, we exclude pulsations with amplitude similar to the one observed by *NuSTAR* in the *XMM-Newton* data. The amplitude of the pulsations in this source, however, has been reported to vary with time, hence it can not be excluded that at the time of the *XMM-Newton* observation it remained intrinsically low. This would imply that pulsations in ULXs powered by accreting neutron stars might be transient and highlights the importance of regular monitoring of ULXs, particularly at higher energies where pulsed fraction is expected to be larger. Still, an independent confirmation of pulsations in ULX in M82 would be indispensable.

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